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Study on Anti-explosion Analysis of Coach Body Based on Occupant Protection

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Abstract: In order to improve the anti-explosion performance, it established a finite element model of coach body under side explosion based on HYPERMESH & LS-DYNA and analyzed its deformation and occupant head injury (HIC) and chest injury (CSI). In view of the serious occupant injury, the paper studied the improvement measures. The results show that it is very effective to fill the foam material between body's trusses. Its deformation is reduced by more than 6%, HIC is reduced by more than 40%, and CSI is reduced by more than 20%. Therefore, the method can effectively improve the anti-explosion performance, and further research on foam's filling type and filling parameters is of great significance.

Key words: coach; explosion shock wave; simulation; deformation; occupant safety.

Introductions

According to GTD data, the world terrorist activity is on the rise during 2001-2008 years, during which 8928 cases of terrorist bombings, accounting for 53.7% of the total number of terrorist incidents [1]. In addition, accidental explosions occurred one after another. The Tianjin harbor incident, the Hebei tunnel tanker explosion and the electric vehicle explosion all caused different injuries to the surrounding vehicles and passengers.

Until present, scholars at home and abroad have only carried out anti-explosion research on military vehicles [2-9] and occupant injury research [10-12], but no public reports and literature on the anti-explosion research of buses have yet been seen. At the same time, military vehicles only do bottom anti landmine research without involving side protection. With the frequency of explosion accidents appearing on the highway, it poses a serious threat to passengers. Meanwhile, most of the highway explosion accidents happen on the side of the road, so the side anti-explosion performance of the bus body is studied in this paper.

1 Building of Model

Because of the destructive and dangerous characteristics of blasting test, simulation has become the main research method of the response characteristics of passenger cars during blasting. The blasting model is composed of two parts: the finite element model of coach and the model of blast shock wave.

1.1 FEM of Coach

Vehicle geometry model is established in CATIA. Referring to a vehicle model, the frame, body skeleton and skin structures are extracted, and a simplified CAD model is built

The finite element model (FEM) of coach is established in HYPERMESH. The CAD model is imported into HYPERMESH for geometry cleaning, meshing, material attributes, establishing connection and contacts and so on. In geometry cleaning, in order to guarantee the quality of the mesh, a hole with a radius less than 5mm and a hole with a diameter of less than 10mm are filled. Due to the large model of body, 40-50mm shell element mesh is adopted for the body framework, and 80-100mm shell element is adopted for the outer skin of the body. The tires are defined by *Airbag in collisions. After meshing, the corresponding materials and attributes should be given, and finally the corresponding welding, riveting and other connection settings are made by connecter. Besides, the contact of the bus body is set to *CONTACT_AUTOMATIC_SINGLE_SURFACE and the contact parts can be assembled into the contact group in the form of *PART_SET and the operation efficiency is high. The ground is defined by *RIGIDWALL_PLANAR and the coach's gravity is added by *LOAD_BODY_Z and the coefficient of friction between the tire and the ground is 0.6. Thus, FEM of coach is established. Through the comparison with the vehicle parameters, including size, mass, center of mass and moment of inertia, the quality of the model is adjusted slightly. The final parameters are obtained: length 12,656mm, width 2,500mm, high 3,170mm, mass 12.7t, centroid (-5706, -9, 1189), moment of inertia around the Z 116.19kg*m2. As shown in Fig. 1.

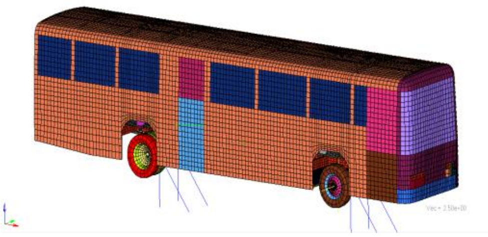


Fig. 1 FEM of coach

1.2 Explosion Impact Model

The explosion shock wave is simulated based on the method of CONWEP, that is, the propagation process of the shock wave pressure is simulated in HYPERMESH according to the empirical formula of the explosion wave propagation. In order to verify the feasibility of CONWEP, we established by square plate explosion model based on the method, the explosion point is located in the center of the sheet below 470mm, the explosive charge is 0.7kg, and constraint sheet edge node all degrees of freedom, as shown in Fig. 2. The results show that the maximum deformation amount of the plate is 66.911mm. According to GUO Qitao[6] and many other tests, the average value is 70mm. So the error of CONWEP is 4.41%. Within allowable range, it can be used in later research.

Fig. 2 anti-explosion model of sheet

According to the anti-explosion modeling of sheet process, boundary conditions and initial conditions, the anti-explosion model of coach is established by loading the explosive equivalent and position, and establishing the corresponding contact in FEM of coach. The explosive parameters are shown in Fig. 3. The explosive equivalent is 10kg, located at the 4.25m of the center of mass of coach.

*LOAD_BLAST

[WGT]	[XBO]	[YBO]	[ZBO]	[TBO]	[IUNIT]	[ISURF]
0.010	-5706.000	-4259.000	1189.000	0.000	5	2
[CFM]	[CFL]	[CFT]	[CFP]			
2200.000	3.280e-03	1000.000	145.030			

Fig. 3 explosive parameters

2 Anti-explosion Analyses

2.1 Effectiveness Analysis

The validity of the simulation can be tested by energy change, and Fig. 4 is the energy change curve of the simulation model. Overall, the total energy of the system is basically equal to the sum of kinetic energy and internal energy, so the hourglass can be less than 5% of the total energy. The simulation results can be trusted.

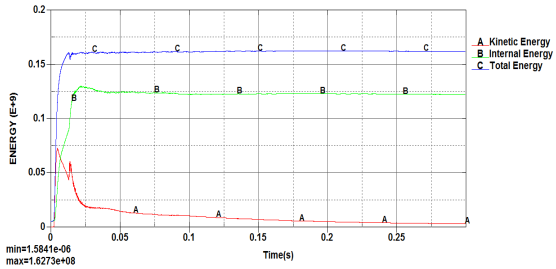


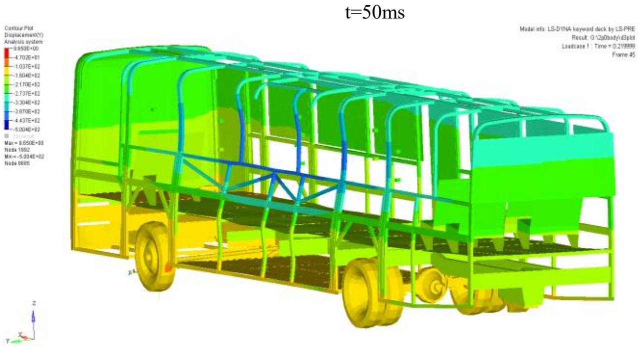
Fig. 4 energy change of simulation model

2.2 Deformation Analysis

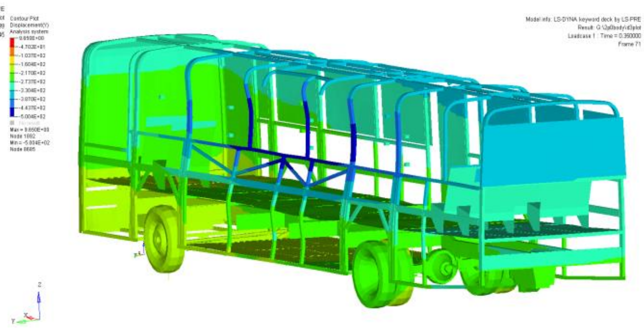
Under the loading of blast shock wave, the body deformation is mainly composed of three stages of rigid displacement, elastic plastic deformation and elastic recovery, and there is no danger of fracture, as shown in Fig. 5. In the beginning of explosion, shock wave instantly effect on the body, and overcome the friction between body and the ground to make the whole vehicle to move to Y. According to the monitoring, vehicle moved by 225mm. With the increase of the distance and reduces the pressure of shock wave, the friction makes the vehicle body frame stop moving. And body begins to bear force and bring elastic-plastic deformation. Because of shock wave is a layer of communication, so the body vibrates and finally has a certain elastic recovery. The place where the deformation occurs most is shown in the oval region of the Fig. 5, near the explosive.

t=50ms

t=160ms



t=280ms



t=350ms

Fig. 5 displacement at different times of explosion

To get a better understanding of body structure deformation, we come to measure deformation of 5 points in the large deformation region. Since there is no plastic deformation of the back surface of coach, the decrease of distance between the left and right sides of the vehicle is plastic deformation. The selected 5 pairs of nodes are 1 (780911279), 2 (865111426), 3 (820712214), 4 (831412339), and 5 (904713204), as shown in Fig. 6. The measured distance of the corresponding points is shown in Fig. 7.

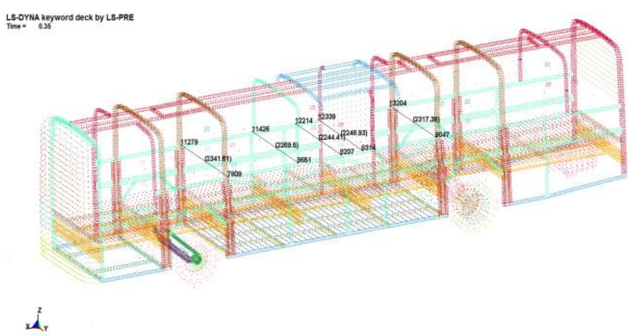


Fig. 6 location of selected deformation points

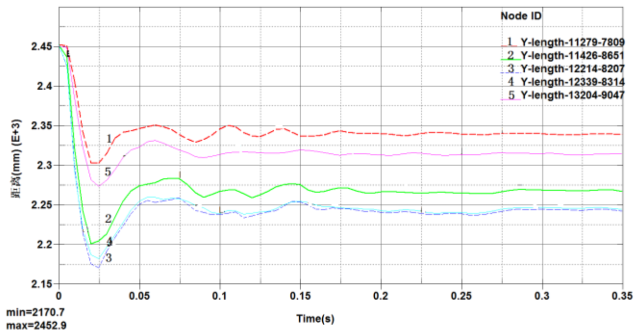


Fig. 7 the distance of each pair of nodes in origin project

The difference between the initial distance and the minimum distance is the maximum invasive value, and the difference between the initial distance and the final distance is the plastic deformation. As can be seen from Fig. 7, the variation trend of the distance between the selected points is basically the same, and the intrusion amount is up to maximum at about 24ms. It is calculated that the maximum invasion and final deformation of each measuring point are shown in Tab. 1.

Tab. 1 invasion and deformation of each measuring point

point	1	2	3	4	5
invasion (mm)	149.5	251.7	282.2	270.1	177.3
deformation (mm)	112.9	187.3	208.3	205.4	135.6

2.3 Analysis of Occupant Safety

Through studying on experiment and Simulation of passenger damage, YANG Songnian [10], ZHANG Qiancheng [11] and Khalis Suhaimi [12] et al describe that wave impact on occupant is mainly that overall acceleration of vehicle and local acceleration produced by body structure deformation beyond the tolerance limit of the human body and lead to head and chest injuries. Here, the acceleration values are monitored by setting an acceleration sensor at the chest and head positions of the plurality of seats, as shown in Fig. 8.

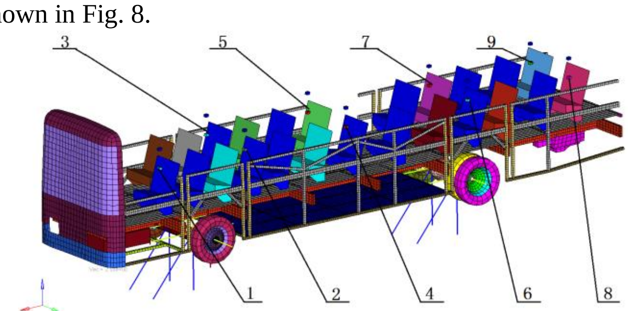


Fig. 8 sensor position

(1) Head injury

The federal motor vehicle safety standard (FMVSS) proposed a formula for calculating the tolerance limit of head injury (HIC), and set HIC15=700 is the linear acceleration tolerance threshold of the head.

$$HIC15=\{(t_2-t_1)(\frac{1}{t_2-t_1}\int_{t1}^{t2}adt)^{2.5}\}_{\max}$$

Where t_1 and t_2 is two moments in collision, $t_2-t_1\leq 15$ ms; a is acceleration of impactor centroid, g.

Using LS-PREPOST to load the output of *nodout data in ASCII, we can get the HIC15 value in each seat, as shown in Tab. 2.

Tab. 2 HIC and CSI for each measuring point

point	HIC	CSI	point	HIC	CSI
1	851	995	6	987	1321
2	2004	1063	7	614	213
3	1125	276	8	342	334
4	8554	2337	9	271	211
5	1959	696			

It's easy to know that HIC of 4, 2 and 5 near the explosion center is larger and far exceed the safety value in this condition of blasting. So the structure needs to be improved; And HIC of 8 and 9 far from the explosion center are small within the scope of the safety.

(2) Chest injury

FMVSS provides that the time of breast synthesis acceleration greater than 60g shouldn't exceed 3ms. At the same time, defined as HIC, the chest injury is defined as CSI, and is required no more than 1000. The CSI at the simulation are shown in Tab. 2.

The trend of CSI is the same as that of the head injury. CSI of 4 is the largest, which is several times the value of the other places. It belongs to the dangerous position under this condition.

3 Improved Designing

3.1 Improvement Project

Generally, the body improvement is mainly carried out in 3 aspects: car body structure, car body material and vehicle interior. Here, the paper improves its anti-explosion performance by filling the foam material between the skeleton, as shown in Fig. 9.

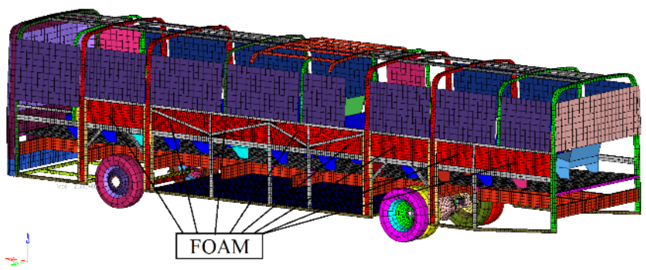


Fig. 9 improvement plan

In simulation, three-dimensional meshes and two-dimensional meshes can easily penetrate each other, resulting in abnormal slip energy and even the suspension of calculation. For this, the foam material is extracted from the 3D mesh surface to form the 2D mesh, and set it as an empty material defined as *MAT_NULL and its density is set to 1.2e-9. Finally, this 2D is set to surface to surface contact with the body defined by *SURFACE_TO_SURFACE. The foam material is defined by the key of *MAT _LOW_DENSITY_FOAM in the LS-DYNA, and its stress-strain curve is shown in Fig. 10.

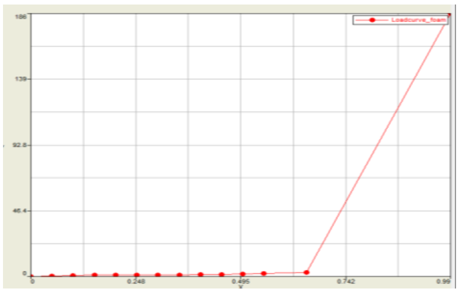


Fig. 10 stress-strain curve of foam material

3.2 Improvement Results

(1) Body deformation

After the improvement, the distance between the 5 pairs of points in the same position is shown in Fig. 11, and the maximum amount of invasion and deformation are compared with those shown in Tab. 3.

It can be seen from the table that the improved scheme can improve the deformation and penetration of each point, reduce the deformation by more than 7.83%, and reduce the intrusion volume by at least 6.84%, which greatly improves the occupant's living space. It is mainly because the foam between the skeleton absorbs a lot of energy, so that deformation can be properly reduced.

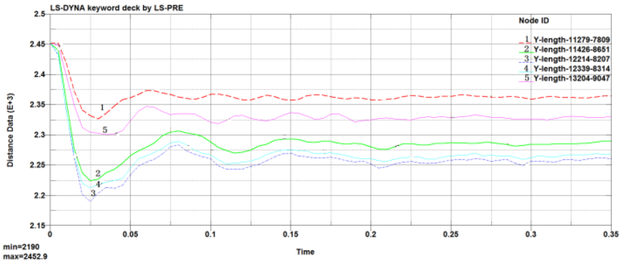


Fig. 11 the distance of each pair of nodes in improved project

Tab. 3 deformation and invasion after improvement

point	invasion（mm）	improvement ratio	deformation（mm）	improvement ratio
1	126.0	15.72%	86.4	23.47%
2	282.2	9.33%	165.0	11.91%
3	262.9	6.48%	192.0	7.83%
4	239.0	11.51%	182.4	11.20%
5	149.8	15.51%	117.7	13.20%

(2) Head injury

Comparison of head injury values before and after improvement as shown in Tab. 4. The head injury has been greatly improved; the value has been reduced by more than half. Especially the most dangerous position of the case, HIC has been reduced by about 80%, which shows that the improvement measures are effective. However, you can see that the HIC value in some locations is above the threshold. This can be solved by optimizing the parameters of the foam material, filling method, and filling capacity.

Tab. 4 HIC and CSI for each measuring point after improving

point	HIC	improvement ratio	CSI	improvement ratio
1	258	69.68%	563	43.42%
2	576	71.26%	524	50.71%
3	417	62.93%	468	-69.57%
4	1484	82.65%	735	68.55%
5	493	74.83%	563	19.11%
6	358	63.73%	649	50.87%
7	224	63.52%	436	-104.69%
8	193	43.57%	522	-56.29%
9	146	46.13%	430	-103.79%

(3) Chest injury

Contrast the chest injury before and after improvement as shown in Tab. 4. The table shows that the CSI of the detonation surface of the vehicle is greatly reduced, while for the back face, the CSI value increases a little. This is mainly due to the influence of shock wave diffraction and circulation on the back surface. But because the back detonation surface is less damaged by the explosion shock wave, the CSI does not exceed the threshold. This amounts to an average part of the damage and is also a way to reduce casualties.

4 Conclusions

(1) Under the condition that 10kg TNT blast in the side of vehicle centroid, the body mainly depends on the skeleton to withstand the impact force and absorb impact energy. So it is prone to large deformation, which causes serious damage to the occupant's head and chest.

(2) After the foam material was filled between the coach body frames, the foam absorbs a great deal of explosion energy, which greatly reduces the deformation and invasion of the skeleton, and the head injury and chest injury of the occupant.

(3) Filling with foam material plays a vital role in occupant safety, which is an effective measure for anti-explosion design. And optimization of its filling structure, parameters and so on will be of greater significance and should arouse concern.

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